CASH-FOR-CONVERSION:

POLICY OPTIONS TO DEVELOP LOW-COST EVS, USING REBATES FOR RETROFITTING CONVENTIONAL VEHICLES.

by

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A capstone submitted to Johns Hopkins University in conformity with the requirements for the degree of Master of Science in Energy Policy and Climate

Baltimore, Maryland

May 2021

Abstract

The transportation sector currently accounts for the largest portion of greenhouse gas emissions in the United States. The light-duty vehicle (LDV) fleet, composed of passenger vehicles and light-duty trucks, makes up the largest source of emissions within the transportation sector. Reducing emissions from the transportation sector requires rapid decarbonization of LDVs. One strategy for rapid decarbonization requires electrification of the LDV fleet. High costs of new electric vehicles and the increasing age of vehicles on the road provide obstacles to rapid electrification. This problem is of greater significance among lower-income groups, who can not afford the cost of EVs, and whose budgets have them purchasing used vehicles, keeping older vehicles on the road longer.

This project explores the feasibility and impact of using existing internal combustion vehicle stock and converting them to battery electric vehicles. The first part of this research explores the challenge of transforming the LDV fleet to electric, the impact on low-income consumers, and the role of policy in enabling vehicle electrification. The second part covers the technical challenges and costs of vehicle conversion. Costs of conversions are then compared to the current electric vehicle market. A comparative analysis, with considered policy options, is conducted and benefits quantified.

The results of the analysis show that there is a large amount of variability in vehicle retrofitting costs. With a targeted rebate policy, retrofitting vehicles to electric can open the EV market to low-income consumers. Retrofits can accelerate decarbonization by providing more low-cost options for electrification while reducing the need to retire the existing fleet. The benefits of a subsidized conversion program are much greater than the costs.

Acknowledgments

I would like to thank my mentor, Dr. Austin Brown, for his guidance and patience with me. He challenged me and taught me to think in different ways that were outside of my comfort zone. Dr. Daniel Zachary for being positive and supportive as I considered changing careers and enrolling in the Energy Policy and Climate Program. My mom and dad, who supported me so I could focus on my studies.

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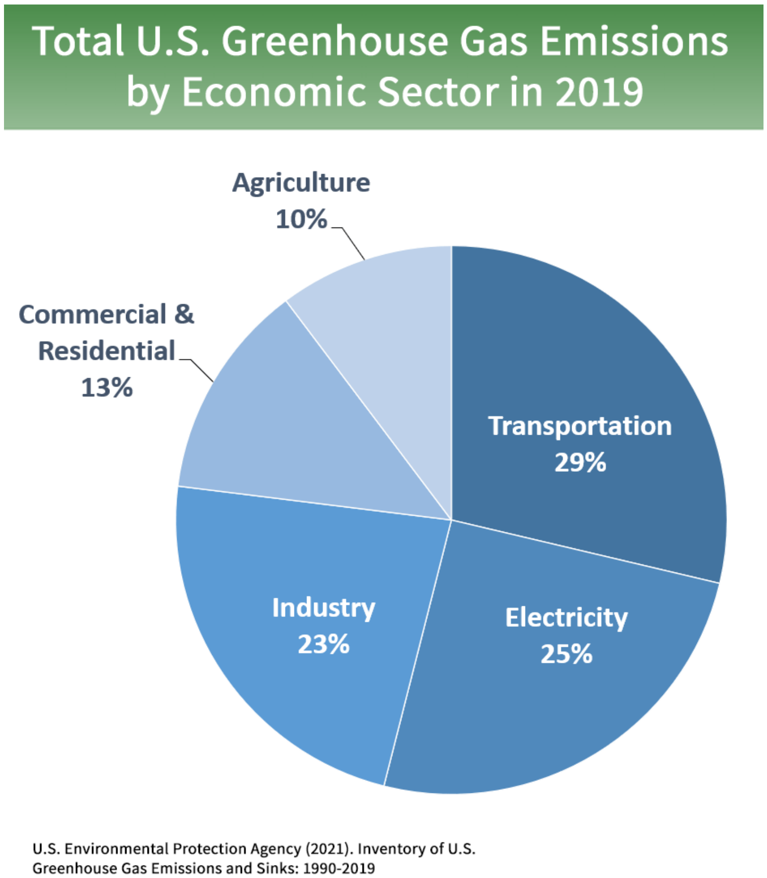
1. Introduction

1.1 Transportation Emissions

To meet the targets set by the IPCC, limiting warming to 1.5 ℃ requires rapid decarbonization of the transportation sector (IPCC, 2018). In recent years greenhouse gas (GHG) emissions from the transportation sector have overtaken electricity generation as the largest source of emissions in the United States (Fig.1.1). Transportation emissions have exceeded power generation emissions because the transition to cleaner forms of transportation has been slow, lagging the transition of the electricity grid. Electricity generation has seen a reduction in carbon intensity from increased efficiency, increased renewables, and the rapid replacement of coal generation. Rapid decarbonization of transport will require the replacement of fossil fuel-powered vehicles. These vehicles are expected to be replaced by battery electric vehicles (BEVs or EVs).

Fig 1.1



The transition of the electricity grid to clean and renewable energy sources will reduce its CO_2 intensity. There are opportunities to lessen the GHG emissions of the transportation sector, by increasing the share of BEVs on the road. BEVs will get energy from the grid and their emission intensity will be directly tied to the emission intensity of the grid. Rapid electrification of passenger vehicles, and light trucks, known as the light-duty vehicle (LDV) fleet, presents the best way to reduce transportation GHG emissions. There are, however, obstacles to the rapid decarbonization of the LDV fleet.

1.2 Fleet Transition Obstacles

Current Li-ion powered battery electric vehicles (BEVs) are advanced technology. The high capital costs required to purchase a BEV is a “barrier to adoption (Adepetu; Keshav, 2017),” and an obstacle to rapid decarbonization. High-income consumers purchase EVs in a much greater proportion to lower-income consumers (Muehlegger; Rapson, 2018). Low-income consumers will purchase what is economically available to them, i.e., used internal combustion engine vehicles (ICEV). A 2003 BLS study found that “people who purchased used vehicles had the least income, on average (Paszkiewicz, 2003).” The result is that low-income consumers are not participating in the EV market.

The inclination for lower-income consumers to purchase used vehicles relates to the second obstacle to the rapid decarbonization of the LDV fleet; the long tail distribution of vehicle survival. This distribution describes how fleet turnover takes a long time. The last 10% of technology takes 20 years to be replaced (Keith; et al. 2019). Low-income consumers, being limited in choice, add to the rate of vehicle survival, delaying the retirement of older vehicles. This slows the rate at which the LDV fleet can increase EV share.

1.3 Objectives

The two obstacles, when considered together, suggest the development of a policy solution. The high costs of EVs are a barrier by excluding low-income consumers from the market. If low-income consumers cannot buy EVs, that reduces the number of potential EV sales and makes increasing EV share more difficult. Low-income consumers cannot afford new vehicles so purchase used vehicles; this increases vehicle survival and decreases vehicle retirement and fleet turnover. A policy that will rapidly decarbonize the LDV fleet will need to:

1. Find low-cost options that allow low-income consumers to gain access to the BEV marketplace.
2. Increase the rate of vehicle retirement.

This study provides an overview of the literature that presents many policy options that can be compared. The United States has experience with policies designed to increase vehicle retirements and rebates which lower the costs of targeted goods for consumers. However, rebates alone may not be adequate to lower the price of new BEVs. The retrofitting of existing vehicles may present an option for a lower-cost BEV. A program that incentivizes vehicle retrofits would provide the least-cost option for EV purchases. In a sense it would increase fleet turnover, however, the turnover would be specific to the component of the vehicle that is needed to be scrapped to achieve rapid decarbonization; the internal combustion engine (ICE). Government funding spent on programs that provide options for low-income consumers will increase EV share, and have positive budgetary benefits, through fuels and carbon savings.

2. Background

2.1 Rapid Transportation Decarbonization

The United States transportation sector is currently the leading source of emission in the nation. The largest sector of this emissions is the light-duty vehicle (LDV) fleet. The United States has 276.5 million highway registered vehicles, of which over 250 million are LDVs (BTS, 2019). These vehicles are responsible for 57.7% of transport emissions or about 33% of total US emissions. Any substantive effort to reduce emissions to meet the IPCC goals will have to develop targeted ways to rapidly decarbonize this sector. The rate of turnover in the LDV fleet indicates that the majority of the 250 million vehicles will have their emissions committed for over a decade. To keep warming below 1.5℃, it is not enough to introduce technologies that will replace internal combustion vehicles. Policies will have to find ways to increase the rate of retirement and scrappage of the existing stock of vehicles (Tong, 2019).

A study by Alarfaj, Griffin & Samaras analyzed the variables that impact the rapid decarbonization of US passenger transport. The three important variables that most strongly impact decarbonization are:

- EV share: The proportion of electric vehicles in the LDV fleet.
- Vehicle Miles Traveled: A metric of use intensity of vehicles.
- CO_2 intensity of the electricity grid: The quantity of carbon emitted per unit of electrical energy (gCO_2e/kWh)

Fig.2.1

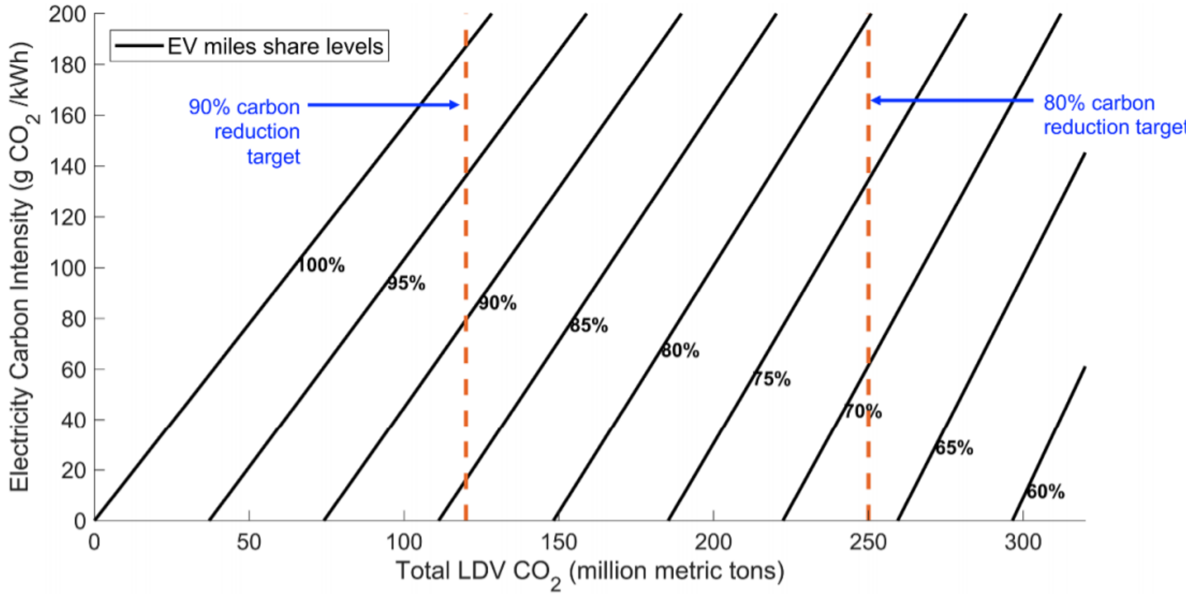


Figure 1. Levels of EV miles share and electricity net generation carbon intensity required for a given 2050 total US Light Duty Vehicle (LDV) CO_2 target and 3.3 trillion miles of LDV travel. The two vertical dashed lines at 250 and 120 million metric tons represent an 80% and 90% reduction in LDV CO_2 from 2005 levels, respectively. The triangle formed by the *x*-axis, a given CO_2 intensity level and the share of EV miles represent the feasible space which shrinks as decarbonization targets become more stringent. The feasibility space approaches a single point (the point of origin) as the decarbonization target approaches zero emissions.

VMT is a difficult variable to move. It is trending towards more miles traveled and requires modal shifts to decrease. Assuming that VMT will be mostly constant, the pathway to rapid transport decarbonization is through the deployment of electric vehicles and low-carbon electricity. The study analyzes two scenarios for decarbonization. An 80% & 90% reduction from 2005 emissions by 2050. Assuming VMT will remain constant, reducing emissions to 80% of 2005 levels will require a grid with zero emissions, and an EV share of 67%. Achieving 90% emissions reduction by 2050 requires a grid with zero emissions and 84% EV share. Fig. 2.1 shows the 80% & 90% reductions in red. The relationship between grid carbon intensity, EV share, and LDV carbon intensity is interdependent. To reach a 90% reduction of 2005 emissions, if the grid had an intensity of 200 g CO_2/kWh, it would require 100% EV share. A grid with a higher carbon intensity requires greater EV share or reduced VMT. Higher VMT requires greater EV share and a cleaner grid. Greater EV share of VMT can substitute for EV share of the LDV fleet; if EVs are traveling a greater proportion of miles, it accomplished the same function as increasing the proportion of EVs in the fleet (Alarfaj et al, 2020). The figure shows that if transportation is going to be decarbonized, higher EV share and a cleaner grid is necessary.

Three key actions must be taken to rapidly decarbonize LDVs. Increasing the proportion of EVs--or the number of miles EVs travel relative to other vehicles--and decarbonizing the grid are the two most likely actions. Reducing VMT is beneficial, but trends show little change in driving behavior (BTS, 2019). If VMT is a constraining variable and reducing VMT is not achievable, "only a narrow region of EV miles and electricity carbon intensity combinations that can meet the climate target (Alarfaj et al, 2020)." Vehicle emissions are on a budget & timeline. The focus is then on rapidly increasing EV share and grid decarbonization.

To achieve the specified emission reduction by 2050, this study will focus on increasing EV share, by accelerating vehicle stock turnover with conversion to electric. Grid decarbonization is worth continued study, but a grid with emissions greater than zero prescribes the need for a greater EV share. Using a zero-carbon grid as an assumption, how can EV share be increased to achieve the needed emissions reductions? The current policy offers subsidies for the purchase of new electric vehicles. This does not adequately address the issue of emissions from the existing stock of vehicles.

2.2 Fleet Turnover

As previously noted, the existing stock of vehicles represents a committed source of emissions. The LDV fleet has been increasing in age; the current average age of a vehicle on the road is now 12 years (IHS, 2020). EV share will be constrained by the turnover of current vehicle stock. The restraining variables are the rate of penetration of new technology, the rate of old vehicle retirement, and the age of vehicle retirement. Adding new vehicles to stock does not force older vehicles out. The stock accumulates, so those new vehicles are added to the number of existing vehicles. Keith, Houston, & Naumov found that if 100% of new vehicle sales were new technology, it would take 19.6 years for the new technology to account for 90% of the vehicles on the road (Fig. 2.2; Kieth et al, 2019).

Fig 2.2

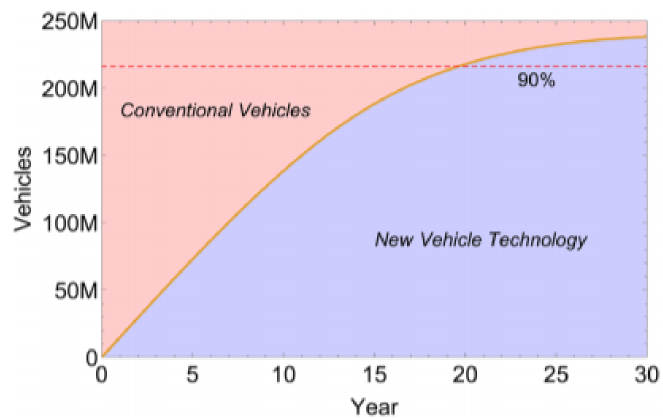
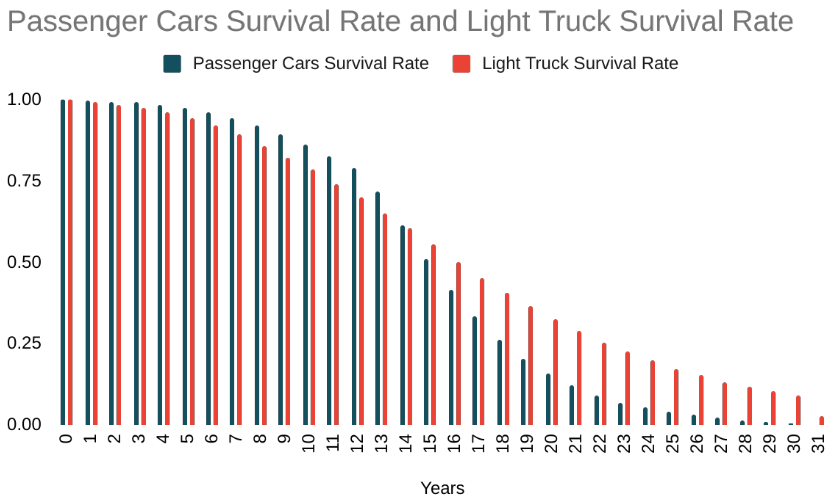


Figure 2. Simulated introduction of a new vehicle technology in the United States.

Fig 2.3

Long-tail of vehicle survival curve



This is the “long tail vehicle survival curve” as shown in Fig. 2.3. The data, from the Environmental Protection Agency, show that vehicles remain in the fleet for up to 30 years. This stock of vehicles is an obstacle to increased EV share. As long as these vehicles remain on the road, they are producing emissions, and new ICEV vehicles entering the stock in the present will have their emission committed for the next 20-30 years, unless they exit the stock early. Alarfaj et al calculate, using current EV sales projections and vehicle retirement rate, that to achieve 100% EV share by 2050, requires 100% of LDV sales to be EV in 2020. Calculations, seen in Fig. 2.4 find that to achieve the 80% GHG reduction by 2050, which required 67% EV share, would require 100% EV sales by 2040. To achieve a 90% GHG reduction, which requires 84% EV share, requires 100% EV sales by 2037 (Alarfaj et al, 2020).

Fig 2.4

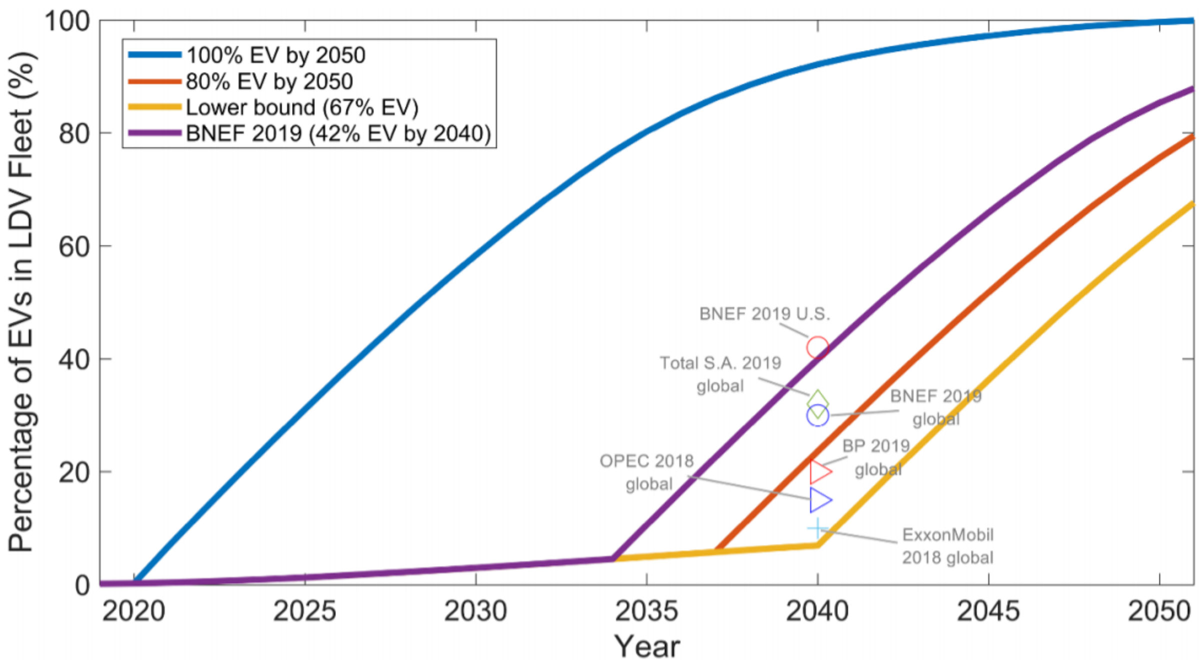


Figure 4. Projections of EV fleet share up to 2050 under different forecasts for the US and global LDV fleets. The lines represent the main cases considered in this analysis that are 100%, 80%, 67%, and the case matching the BNEF 2019 forecast of 42% EVs in US LDV by 2040 [69]. Points with US and global projections by others are shown for comparison [69–72].

The rapid decarbonization of the LDV fleet will require policies that greatly increase the rate at which EVs are introduced into the market. However, incentives that increase the rate of new technology entry are not enough for rapid decarbonization. Policies must also induce the early retirement of existing carbon-emitting vehicle stock (Alarfaj et al, 2020). The United States has already attempted such a policy.

2.3 C.A.R.S.

The 2009 American Recovery and Reinvestment Act (ARRA) included a program that offered a rebate to trade in older vehicles in exchange for new vehicles with improved fuel economy. The Car Allowance Rebate System (CARS) was initially considered a great success by policy makers and was popular with the public. It exhausted the allocated one billion dollars in funding in the first month. It was refunded and, again, exhausted those funds earlier than expected (Li, Linn, Spiller, 2013). Further analysis showed that there were many flaws in the program that could be improved upon. It was an inefficient way to use funds to reduce fuel use. The amount of fuel saved on traded-in vehicles was low compared to national fuel use. Its climate benefits were minor. The economic stimulus the program was credited with was overstated (Gayer, Parker, 2013). Multiple analyses have shown that this was not the best structure for this program.

The CARS program's primary purposes were economic stimulus, reducing emissions, and assisting consumers (Busse, Knittel; Silva-Risso; Zettelmeyer, 2012). With a final budget of $3 billion, it was responsible for the selling of 700,000 new vehicles (Gayer, Parker, 2013). The average fuel economy of a new vehicle was 9.2 mpg higher than the vehicle that was scrapped.

Though the popularity of the program and immediate impacts were initially impressive, later analysis showed that it was highly inefficient for its stated purposes. The program was too small to be significant, affecting only 1% of vehicles on the road. It failed to make a lasting impact as an economic stimulus; it had pulled vehicle sales forward a few months, instead of stimulating new sales (Gayer, Parker, 2013). Emission reductions and fuel savings were marginal. The program reduced fuel use between 925 to 2,907 million gallons and resulted in a carbon emissions reduction of 9.00-28.2 metric tons. Emissions reductions cost taxpayers between $92 to $288 per ton of CO_2 (Li, Linn, Spiller, 2013). Knittel calculates that the implied costs of carbon in the CARS program were between $250-450 per ton of CO_2 (Knittel, 2009).

The Cash for Clunkers program was an inefficient way to lower fuel use, reduce emissions, and stimulate the economy. Where the program structure succeeded was that it encouraged the retirement of 700,000 existing vehicles from the fleet. Rapid decarbonization of the LDV fleet and increased EV share require a program that accelerates the rate of vehicle scrappage; a “trade-in-&-scrap for rebate” program will have some utility.

2.4 Income Disparity & Program Design

DeShazo, Sheldon, & Carson analyzed how different program design elements have varying effects on targeted objectives. Income and price caps lower the amount of higher-income consumers that would have used a rebate to purchase a new EV. Since new EVs are affordable to this group of consumers, they do not need the rebate and would have purchased an EV without the rebate. Therefore, the use of the rebate by high-income consumers is wasteful and an example of “free-riding.” Free-riding limits the number of rebates available to other consumers and doesn’t produce additional EV sales. Scaled, progressive, or high subsidies do result in increased EV purchases by middle and lower-middle-income groups (DeShazo, et al., 2017). However, low-income groups purchase EVs at far lower rates than high-income groups. (Lee, et al. 2019). The high cost of EVs is a barrier to adoption (Adepetu; Keshav, 2015), placing new EVs outside of the economic reach of low-income consumers.

Guo & Kontou confirms the disparity between low-income consumers and EV adoption. The allocation of rebates in California’s Clean Vehicle Rebate Program was found to be predominately used by higher-income consumers. The bottom 50% of census tracts received approximately 10% of EV rebates and the bottom 75% received 38% of rebates. The top 12.5% received 25% of the rebates. After the enactment of price and income caps, rebate share shifted towards lower-income groups, though still not in an equitable distribution (Guo, Kontou, 2020).

Fig 2.5 shows the disparity with low-income consumers who receive very little of the rebates, even after price limits were put in place.

Fig 2.5

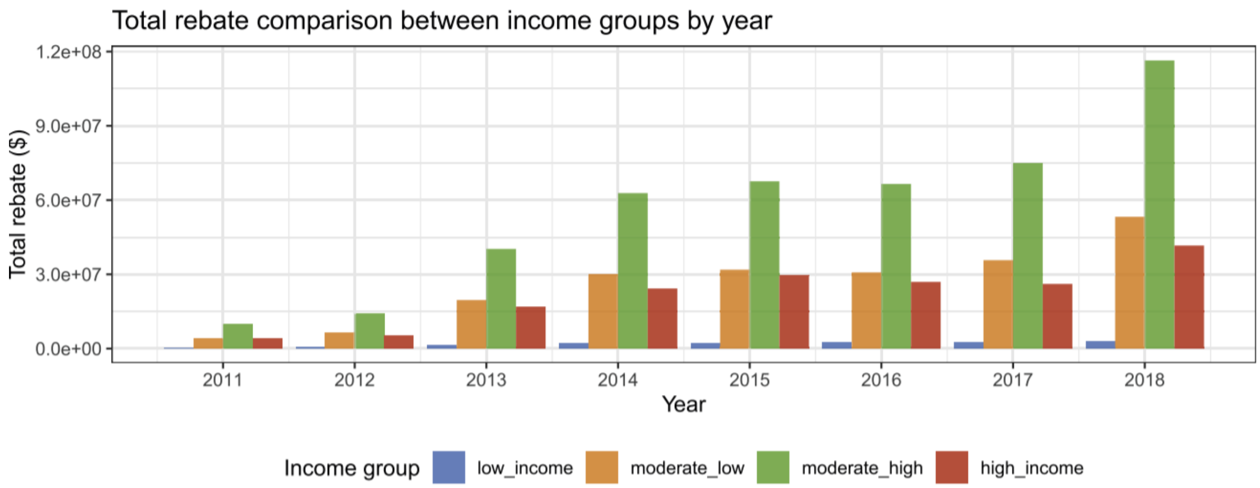


Fig. 8. The total PEV rebate amounts leveraged by different income groups over the years.

The study on rebate design options, by DeShazo, et al., provides a clear template for how a rebate structure needs to be structured if it is to maximize impact with low-income groups. Price and income limits help reduce “free riding,” and preserve program funds for consumers who would not have purchased the EV without the rebate. Large rebates combined with a price or income cap are more cost-effective compared to a status quo baseline. This design element results in the largest quantity of induced additional EV sales with lower total program costs.

A progressive rebate allocates $7,500 to the lowest income levels and excludes rebates for high-income earners. This causes a small decrease in EV sales, reduces total program cost, and increases the cost-effectiveness of the program. An explanation for the greater program cost-effectiveness is that “free-riding” is reduced and more funds are inducing new EV sales. More low-income consumers purchased EVs, however, induced new EV sales amongst low-income groups were not as high as the loss from reducing or eliminating rebates for middle, and high-middle-income consumers (DeShazo, et al., 2017).

Large rebates for low-income groups increase EV adoption by making EVs more affordable (Tbl. 1). “Income classes are typically more responsive to the rebate dollars due to their higher marginal utility of income (DeShazo, et al., 2017).” To create a program that is the most equitable, cost-effective, increase fleet turnover, and increases EV share, a program would need higher value
rebates, with the highest rebates allocated to the lowest-income consumers, and price limits.

Table 1

Table 11
Optimal policy for the status quo budget.

		BEV	Rebate	PHEV	Rebate	Additional PEVs Sold	Total Cost Effectiveness	Total Cost
Optimal Policy	Under $25 k	$	12,500	$	7775			
	$25–$50 k	$	7400	$	2500			
	$50–$75 k	$	–	$	–			
						12,995	$ 22,394	$291,019,864
	$75–$100 k	$	2500	$	–			
	$100–$175 k	$	–	$	–			
	Over $175 k	$	–	$	–			

2.5 Costs Barriers

To rapidly increase EV share, a well-designed policy would incentivize vehicle retirement and provide large rebates for low-income consumers, to increase vehicle affordability. New EVs with rebates are still high cost and will continue to present a barrier to adoption, particularly with low-income groups (Adeptu; Keshav, 2015). Manzel finds that incentives have positive effects on BEV market penetration, and the magnitude and availability of incentives are influential (Münzel, et al., 2019). According to Narasimhan & Johnson, incentives are more effective when targeting low-price EVs and rebates are more effective than tax credits (Narasimhan; Johnson, 2019).

To maximize the amount of EVs available to low-income consumers, low-cost options need to be discovered. All new vehicles, and more so EVs have high upfront costs that put them out of reach for purchase. As a result, low-income consumers favor buying used vehicles. Muehlegger & Rapson explain that “ICE... buyers with incomes below $100k account for 72%...of purchases… high-income buyers account for a disproportionately high fraction of alternative fuel vehicle purchases (Muehlegger, Rapson, 2018).”

Low-income consumers' reliance on used vehicles presents another barrier to rapid decarbonization. It is integrated with the long tail of vehicle survival. Reliance on the secondary market provides demand for used vehicles, increases vehicle survival, and lowers the rate of turnover of the LDV fleet. The scarcity of used EVs for the foreseeable future limits the options for low-income consumers to access the EV marketplace.

The slow penetration of EVs into the LDV fleet and the slow rate of turnover implies that used EVs will be scarce for a significant amount of time. This denies low-income consumers low-cost EV options and presents used combustion engine vehicles as the only affordable option. In the absence of a healthy stock of EVs in the secondary market, policies should develop low-cost options for consumers. One option would be the conversion of existing vehicles into EVs. This would utilize the already low-cost used vehicle market. Rebates would reduce the cost to the consumer of converting the vehicle. If affordable conversion practises can be developed, it opens the potential for very low-cost EVs for low-income consumers, giving them access to the market.

2.6 Conversions Requirements

Retrofitting an internal combustion vehicle to electricity is an intensive process, though not overly complicated. To start, the internal combustion engine (ICE) must be removed, as well as fuel systems. Depending on the vehicle, other parts of the drivetrain, such as the transmission, transfer cases, or driveshafts, may be removed. An electric motor, AC or DC will replace the ICE. The electric motor is significantly smaller than an ICE, and there is flexibility on where it is located. The most straightforward method would be to use an adaptor to attach the motor to the existing transmission.

Fuel tanks and fuel lines will be removed. Depending on the vehicle this will provide some space for a battery pack. Batteries may be located in other open spaces, depending on the vehicle. Placement of the battery-pack will generally be the most difficult task. Not every vehicle will have enough space, which will result in low-capacity batteries with short ranges, or having batteries take up interior vehicle storage space. This has to be approached on a model, by model basis, and requires creative thinking.

Battery and motor controller will need to be installed, as well as updated electronics to manage the motor and batteries. These should fit in the extra space in the engine bay.

Brakes will have to be adjusted to work as a regenerative braking system. These are not considered to be a major expense or difficulty.

HVAC systems can be difficult. Previous systems were operated by the mechanical work of the engine or utilized waste heat. New systems will have to be electric. This is more an issue of cost and power management. Installations should be straightforward because most of the existing ductwork can be utilized.

There are other balances of systems costs. Much of the cost will be in the electric motor, charge/motor controllers, and the most significant cost will be the battery pack.

The labor required is extremely variable with high uncertainty. Estimates range from four hours to “months,” depending on the vehicle and scope of work.

3. Methodology

3.1 Conversions

To establish a range of conversion pricing, this study utilized industry research. The conversion of ICEVs to EVs at this moment is a boutique industry. Businesses that provide conversion services professionally are scarce and operate at low volumes. Without any professional organization, these shops had to be found through a web search or automotive magazine stories:

> EVs of America: A parts supplier that sells components for converting a large variety of vehicles to electric. EVs of America provides price sheets for a variety of conversion systems. These include AC or DC drive systems, battery management systems, instrumentation, braking, and safety systems. Battery prices are not included in these price lists. The only battery options on the website were for Lithium Iron Phosphate (LiFePO) batteries, which are not ideal for transport applications. The price lists given varied on the output voltage, with lower voltages being lower in costs. Higher output motors were all within $2,000 in cost. The AC-51 system was chosen for its higher output and higher costs (see Appendix A).[1]
>
> New Electric Ireland: An EV conversion company based in the Netherlands with another shop in Ireland. Converts vehicles and fleets to electric. Current conversion cost ranges from €10,000-100,000 depending on vehicle weight and range. Kevin Sharpe, operator of the New Electric Ireland, citing Moore's Law, optimistically projects that conversions will drop in price and cost €2,000-5,000 and achieve up to 150-200mi (Irish EVs, 2020). This optimistic projection was used to represent potential future conversion costs. [2]

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[1] http://www.evamerica.com/index.html
[2] https://www.newelectric.nl/automotive/

PowerBattery: PowerBattery is a Dutch battery pack designer. They provided a range of estimates for various components needed to convert a vehicle to electric. A mean of costs was used to develop the estimate. PowerBattery provides battery pack prices that cost $700-800kWh/hr. These are far higher than current industry amounts and were omitted.[3]

Transition-One: A company that performers conversions in France and is government sanctioned. Their focus is on smaller front wheel drive vehicles. Conversion costs less than $5000 with the benefit from a subsidy. Transition-One states their conversions take only 4 hours to complete. This estimate is included because they are a sanctioned and professional business that benefits from subsidies that are a subject of this study.[4]

EV West: EV West is a parts supplier. They sell a large amount of equipment for converting EVs. They have a large selection of conversion estimates, ranging between $15,000-20,000. These estimates were specific to certain vehicles, all of which were collectables. EV West estimates were omitted from the study.[5]

EV4U Custom Conversions: This comes from an individual who converts vehicles and provides a detailed table of conversions cost on youtube. Estimates ranged between $19,000-$30,000. These cost estimates were omitted because the costs were based on older equipment and battery prices that do not match new outputs and prices.[6]

Oz Motors; London Electric: Estimates range from $20,000-27,000. Like EV West, these conversions were for collectables, and were omitted (Clenfied; Watanabe, 2019).[7]

Zero Labs; Twisted Automotive; E.C.D. Automotive Design: US-based business that converts specific vehicles: Land Rovers or 1st generation Ford Broncos. These conversions went beyond the drivetrain and were entire vehicle remodels. Costs for conversions ranged from $150,000-250,000 and would be completed in months-long

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[3] https://www.powerbattery.nl/resources/blog/how-much-does-an-electric-conversion-cost/
[4] https://transition-one.eu/retrofit-cars/
[5] https://www.evwest.com/catalog/index.php?cPath=40
[6] https://www.youtube.com/watch?v=lEQoKTjsRMo&ab_channel=EV4UCustomConversions
[7] https://www.bloomberg.com/news/features/2019-01-10/the-new-hot-rods-are-vintage-classics-with-electric-motors

timeframes. These estimates were omitted from the study because the conversions were too specific and were beyond what was necessary for this study.[8]

Battery pack costs were calculated with the assumption that converted vehicles would have a minimum of 150 miles range. Efficiency was assumed conservatively at 2mi/kWh. The battery price points were selected for a high, medium, and low costs estimate. High costs estimate for battery packs are $250/kWh and were chosen from approximate prices of battery packs sold from conversion shops online. Medium costs estimates are $160/kWh, approximating the $157/kWh, the 2019 average Li-ion battery price reported by BNEF (BNEF, 2020). This price point was selected because these are currently achievable prices if conversion shops can purchase batteries in volume. Low-cost estimates are $100/kWh representing cost required for BEVs to reach cost parity with ICEVs, as projected by BNEF (see Appendix C). This assumes continued rapid reduction in the costs of Li-ion batteries, and conversions done at volume to allow business to take advantage of scale economies.

3.2 New Electric Vehicles

A list of electric vehicles, available now or by next year, was developed. The market sale retail price (MSRP) of each vehicle was used as the price point for comparison with the conversion estimates. Vehicles which cost over $65,000 were not included in the comparison. The $65,000 limit represents the “price cap” seen in some programs that subsidize EVs. The Audi e-Tron ($65,900) was included to provide scale. The $7,500 federal EV tax credit was subtracted from

[8] https://www.zerolabs.com/; https://www.twistedautomotive.com/en-US/; https://ecdautodesign.com/

all new EVs, as an assumption that all new EVs would benefit from the extension of that subsidy.

Table 2

Make	Model	Year	MSRP	Source
Chrysler-Fiat	Fiat 500-e	2021	$30,000	Car & Driver
Volkswagen	e-Golf	2021	$31,895	Edmunds
GM/Chevy	Bolt	2021	$36,500	Edmunds
Tesla	Model 3	2021	$37,490	Edmunds
Tesla	Model Y	2021	$39,990	Edmunds
Ford	Mustang Mach-E	2021	$42,895	Edmunds
Hyundai	Ioniq 5	2021	$45,000	Car & Driver
Volvo	XC-40	2021	$53,990	Car & Driver
GM/Chevy	Cadillac Lyriq	2022	$60,000	Motor Trend
Volkswagen	Audi e-Tron	2021	$65,900	Edmunds

On or soon to be on market electric vehicles.

A range of rebate amounts is applied to the conversions.

- No Rebate: For a baseline comparison
- $2,500 Rebate
- $5,000 Rebate: Approximate size of the retrofit rebate in France
- $7,500 Rebate: Size of Federal tax credit for the purchase of an EV.
- $10,000 Rebate: Approximating the rebate amount for a program with a progressive structure designed to increase EV share in low-income consumers.

3.3 Cost/Benefits Calculation

Government funding a program that retrofits vehicles would have a large cost, and it raises questions of if it is the best use of public money. To see the effectiveness of this program, a net present value calculation of cost and benefits must be made. This calculation looks at the effect of a program on a consumer over 5- & 10-year periods. The discount rate is assumed to be 7% and 3%. The selected rebates amounts are assumed at $5,000 and $7,500.

Benefits from carbon reduction and decreased fuel use are considered. The price of gasoline is assumed at $2.89/gpe, approximately the US average price. The price of electricity is assumed at $0.13/kWh. Avg. fuel economy is assumed at 22.2 mpg, and EV efficiency, 2kWh/mi. The price of carbon was set at $51/ton.[9]

Two different program sizes were selected. The first program uses the $174 billion set aside for EVs in the Biden Administration's Infrastructure proposal. It assumes that 5% funding is used for conversions. This will show how effectively a set pool of money can be used, how many EVs can be converted.

The second program assumes that 5% of the 250,000,000 LDVs on the road will be funded for conversion to EV. This will calculate the cost of a program that is designed to convert a specific proportion of vehicles.

[9] https://www.scientificamerican.com/article/cost-of-carbon-pollution-pegged-at-51-a-ton/#:~:text=Contributing%20to%20climate%20change%20is,to%20about%20%2451%20per%20ton.

3.4 Limitations

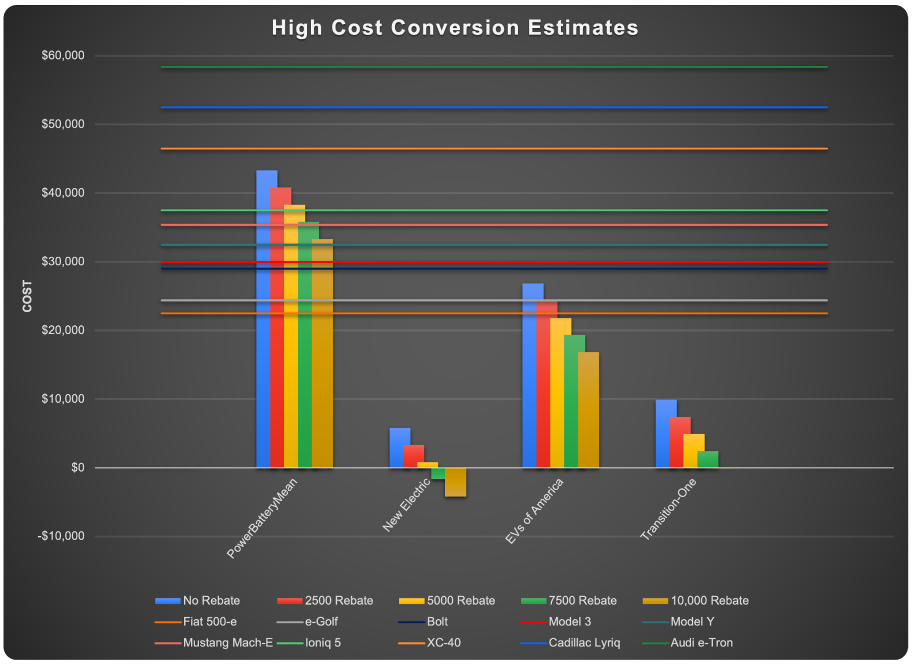
The boutique and specialized nature of vehicle conversions make many of these estimates unreliable. These costs were based on statements made for good publicity or a desire to sell a product. There is a high amount of variability in conversion costs. The estimates were chosen based on what had greater details, what was considered potentially possible, and what is being done with government support. Some estimates do not include labor, however, the lowest cost estimates do include labor. Based on the lower costs estimates, the study assumes that standardized practices and experienced labor will drop the price of labor. There is still a large amount of uncertainty in conversion costs, and these results (excluding the Transition-One estimate) should be viewed as hypothetical and looking to what may be possible.

The cost-benefits analysis does not consider many variables. Both sets of calculations fail to consider the value of equity. Higher rebates will lower the number of vehicles converted, or increase the costs of the program, however, a program that is designed to increase EV share amongst low-income consumers needs to value that objective. The greater the rebate, the more accessible it is to the lower-income groups, however with limited program size, it constrains the number of low-income consumers who can participate. Quantifying equity will require further study. The value of carbon savings from recycling the vehicle body is also not calculated. As discussed later, there are carbon savings in avoiding the production of entirely new vehicles.

4 Results

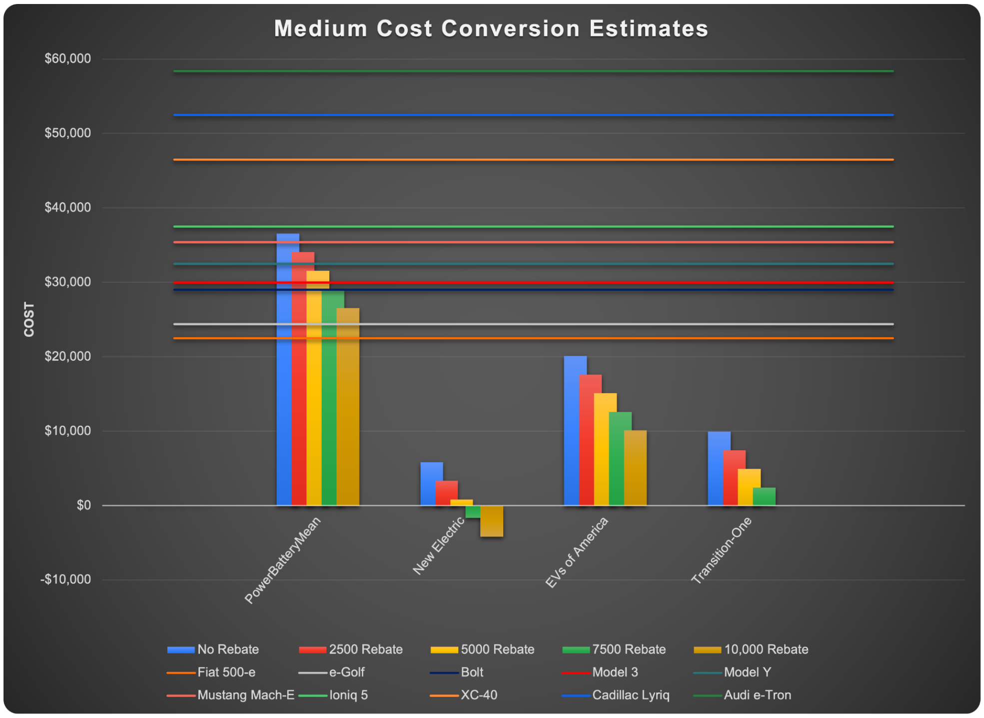
4.1 Conversion estimate comparison

Fig 4.1



Using estimated battery costs in the higher range of the analysis and with rebates applied, fig. 4.1 shows that the PowerBatteryMean estimate is comparable to the cost of some lower-mid-priced EVs. With no rebate, conversion costs would place it in the range of the Volvo XC-40 SUV. Progressive rebates would place it in the low $30,000s, comparable to a Tesla Model Y. The EVs of America estimate, without a rebate, has a high price of over $20,000; this is comparable to lower-cost new EVs such as the Volkswagen e-Golf, Fiat 500-e, and Nissan Leaf (not listed). With a $5000 rebate, the conversion becomes lower in cost than the lowest cost new EV, the e-Golf.

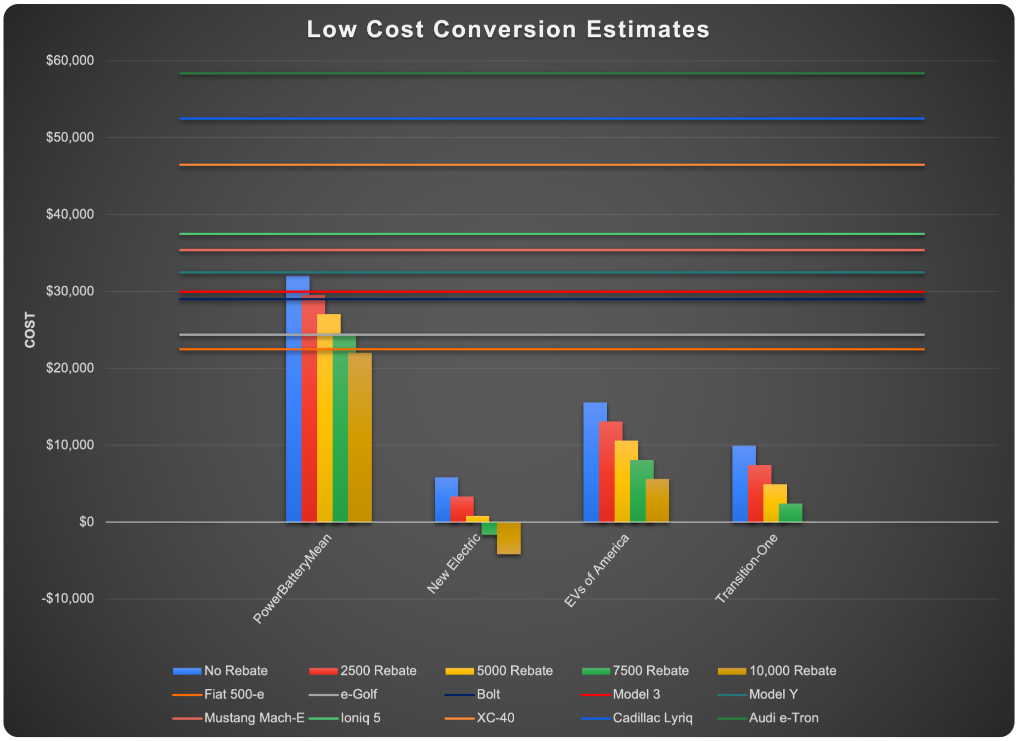
Fig. 4.2



Using medium-range battery prices drops the cost of conversions by over $6,000. The PowerBatteryMean estimates, without rebates, are still in a range that would be outside of the ability for low-income consumers to afford. With progressive rebates, the PowerBatteryMean estimate becomes comparable in costs to the lower-costs new EVs. With mid-range battery costs, the EVs of America estimate is around $20,000, lower in costs than the e-Golf (Fig 4.2). Progressive subsidies decrease conversion costs closer to 10,000.

When the $100/kWh battery price assumption is used, and rebates are applied to the PowerBatteryMean estimate, costs decrease to price points similar to the more affordable new EVs. A $10,000 rebate makes this conversion estimate lower in costs than all-new EVs but still over $20,000. The EVs of America estimates become extremely affordable. Without a rebate, the cost of this conversion is around $15,000. $7,500 and $10,000 rebates bring the costs of this conversion below $10,000.

Fig. 4.3



The cost estimates sourced from New Electric and Transition-One, show that large subsidies will make the conversion to EVs extraordinarily low-cost. New Electric's conversion started at $5,850. A $5,000 rebate drops the conversion below $1,000. Larger rebates have costs go negative (Fig. 4.3). The Transition-One estimates started at $9,945. The $5,000 and larger rebates drop the price below $5,000 for a conversion. A $10,000 rebate results in a negative value. Three estimates show that rebates could result in no-cost conversion for low-income consumers.

4.2 Benefits

Fig. 4.4

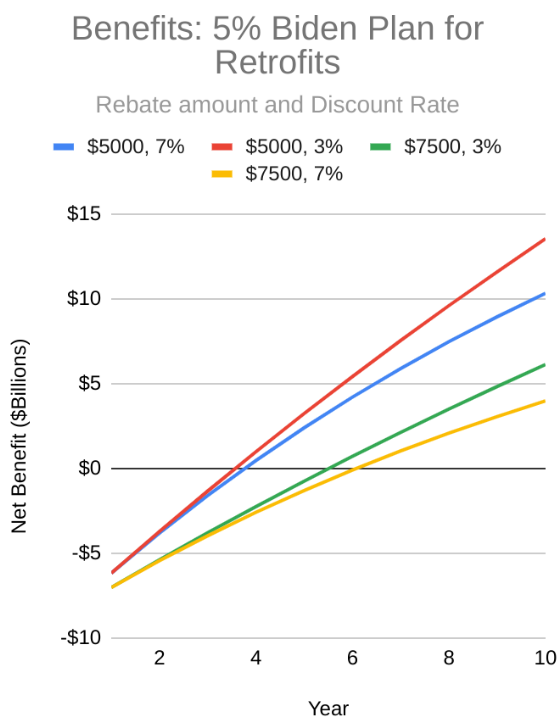
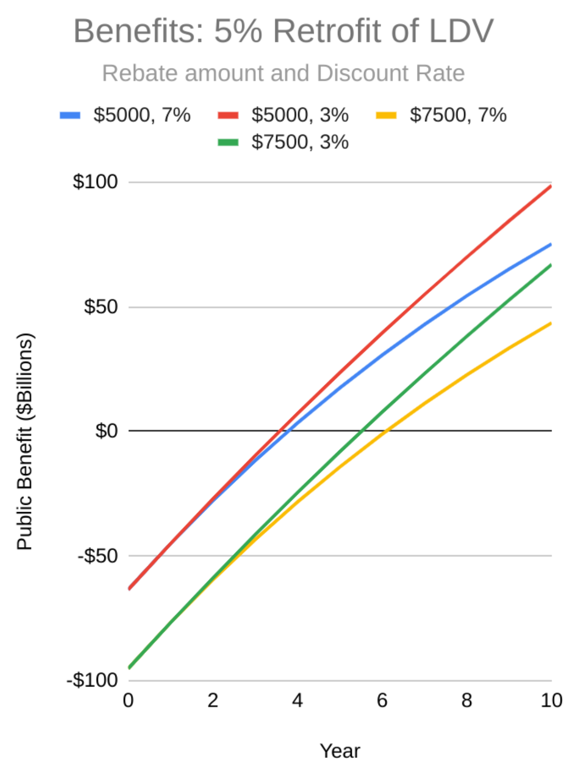


Fig. 4.5



The results of the NPV calculations show that a conversion program would have large benefits for low-income consumers and emissions savings. Switching converting an owned internal combustion vehicle to electric would save the consumer around 700 gallons a year, depending on vehicle efficiency and vehicle miles traveled. This would result in $8,000 to $9,500 in fuel savings over 10 years. Money saved on fuel increases with lower fuel economy of the internal combustion engine, or the efficiency of the converted EV improves.

If the program were designed to use 5% of funding from the $173 billion earmarked for electric vehicles, in the Biden Administration's infrastructure plan, the project's cost would be $8.7 billion. Fuel switching away from gasoline would result in fuel and carbon savings. Using a high discount rate of 7%, the 10-year benefit of the program is $10.3 billion if the rebate is $5,000.[10] 1.74 million vehicles would be converted. With a $7,500 rebate, the benefit is $4.0 billion. 1.16 million vehicles would be converted.

Using the low discount rate at 3%, savings increase to $13.5 billion for the $5,000 rebate and $6.0 billion for the $7,500 rebate. Within the 5 years' time frame, the program is still negative with a 7% discount and $7,500 rebate. It has broken even with a 3% discount (fig. 4.4).

[10] OMG suggests using 7% & 3% discount rates for use in government program calculations (OMB Circular 4-A).

Table 3

PROGRAM COST	$8,700,000,000	PROGRAM COST	$8,700,000,000
Program Size (Vehicles Converted)	1,740,000	Program Size (Vehicles Converted)	1,740,000
Discount	7%	Discount	3%
Rebate:	$5,000	Rebate:	$5,000
Ind.Vehicle Fuel Savings (gallons)	743.2	Ind.Vehicle Fuel Savings (gallons)	743.2
10-year Ind. Savings	$8,144	10-year Ind. Savings	$9,522
Annual Program Fuels Savings	$1,885,677,973	Annual Program Fuels Savings	$1,885,677,973
Annual Program Carbon Savings	$646,362,973	Annual Program Carbon Savings	$646,362,973
5-year Program Fuel Savings	$8,272,867,629	5-year Program Fuel Savings	$8,894,928,555
5-year Program carbon savings	$2,835,730,911	5-year Program carbon savings	$3,048,957,747
10 Year Fuel Saving (PV)	$14,171,307,913	10 Year Fuel Saving (PV)	$16,567,772,062
10 Year Carbon Savings (PV)	$4,857,567,859	10 Year Carbon Savings (PV)	$5,679,015,484
Net Benefit	**$10,328,875,772**	Net Benefit	**$13,546,787,546**
Program Size (Vehicles Converted)	1,160,000	Program Size (Vehicles Converted)	1,160,000
Discount	7%	Discount	3%
Rebate:	$7,500	Rebate:	$7,500
Ind.Vehicle Fuel Savings (gallons)	743.2	Ind.Vehicle Fuel Savings (gallons)	743.2
10-year Ind. Savings	$8,144	10-year Ind. Savings	$9,522
Annual Program Fuel Savings	$1,257,118,649	Annual Program Fuel Savings	$1,257,118,649
Annual Program Carbon Savings	$430,908,649	Annual Program Carbon Savings	$430,908,649
5-year Program Fuel Savings	$5,515,245,086	5-year Program Fuel Savings	$5,929,952,370
5-year Program carbon savings	$1,890,487,274	5-year Program carbon savings	$2,032,638,498
10 Year Fuel Saving (PV)	$9,447,538,609	10 Year Fuel Saving (PV)	$11,045,181,375
10 Year Carbon Savings (PV)	$3,238,378,573	10 Year Carbon Savings (PV)	$3,786,010,322
Net Benefit	**$3,985,917,181**	Net Benefit	**$6,131,191,697**

5% of $174 billion Program for conversion

Using a different program design, with the goal replacing 5% of the 254.0 million LDV fleet (BTS, 2019), the program's size would be 12.7 million vehicles to be converted to electric. A $5,000 rebate would result in a program costing $63.5 billion. Using a 7% discount rate, benefits are calculated to be $17.6 billion after 5 years, and $85.3 billion after 10 years. Using the 3% discount, benefits are calculated to be $23.7 billion after 5 years and $98.8 billion after 10 years.

When the $7,500 rebate for conversions is calculated, the program costs come to $95.2 billion. With the 7% discount rate applied, the program has cost the government $14.2 billion in 5 years, and after 10 years, there are $43.6 billion in benefits. Using a 3% discount the benefits are calculated at $-8.06 billion after 5 years, and $67.1 billion after 10 years (Fig. 4.5).

Table 4

PROGRAM SIZE (Vehicles Converted)	12,690,700	PROGRAM SIZE (Vehicles Converted)	12,690,700
Program Cost	$63,453,500,000	Program Cost	$63,453,500,000
Discount	7%	Discount	3%
Rebate:	$5,000	Rebate:	$5,000
Ind.Vehicle Fuel Savings (gallons)	743.2	Ind.Vehicle Fuel Savings (gallons)	743.2
10-year Ind. Savings	$8,144	10-year Ind. Savings	$9,522
Annual Program Fuels Savings	$13,753,203,133	Annual Program Fuels Savings	$13,753,203,133
Annual Program Carbon Savings	$4,714,252,058	Annual Program Carbon Savings	$4,714,252,058
5-year Program Fuel Savings	$60,338,207,598	5-year Program Fuel Savings	$64,875,212,533
5-year Program carbon savings	$20,682,419,695	5-year Program carbon savings	$22,237,590,854
10 Year Fuel Saving (PV)	$103,358,515,710	10 Year Fuel Saving (PV)	$120,837,140,752
10 Year Carbon Savings (PV)	$35,428,699,096	10 Year Carbon Savings (PV)	$41,419,932,068
Net Benefit	**$75,333,714,806**	Net Benefit	**$98,803,572,820**
Program Cost	$95,180,250,000	Program Cost	$95,180,250,000
Discount	7%	Discount	3%
Rebate:	$7,500	Rebate:	$7,500
Ind.Vehicle Fuel Savings (gallons)	743.2	Ind.Vehicle Fuel Savings (gallons)	743.2
10-year Ind. Savings	$8,144	10-year Ind. Savings	$9,522
Annual Program Fuels Savings	$13,753,203,133	Annual Program Fuels Savings	$13,753,203,133
Annual Program Carbon Savings	$4,714,252,058	Annual Program Carbon Savings	$4,714,252,058
5-year Program Fuel Savings	$60,338,207,598	5-year Program Fuel Savings	$64,875,212,533
5-year Program carbon savings	$20,682,419,695	5-year Program carbon savings	$22,237,590,854
10 Year Fuel Saving (PV)	$103,358,515,710	10 Year Fuel Saving (PV)	$120,837,140,752
10 Year Carbon Savings (PV)	$35,428,699,096	10 Year Carbon Savings (PV)	$41,419,932,068
Net Benefit	**$43,606,964,806**	Net Benefit	**$67,076,822,820**

Program to convert 5% of LDV fleet

5. Discussion

A policy to rapidly decarbonize the transportation sector will require programs that increase EV share, decrease vehicle survival, and provide low-cost options for low-income consumers. These objectives can be met with a program that offers rebates for converting ICEVs to electric.

This study has shown that there are pathways for low-cost EV retrofits. Combined with progressive rebates, conversions could potentially be no cost to the consumer. Recalling the impacts of incentives on EV adoption and their increasing effectiveness as vehicle costs decrease, rebates that lower EV cost to near zero would greatly increase adoption among low-income groups, whose primary barrier to EV ownership is high costs.

The conversion of existing vehicles would also help address the long tail of vehicle survival. Technically, the vehicle may not be retired, but the removal of the ICE decarbonized the vehicle, increasing EV share, and mitigating the barrier that vehicle survival rates present to fleet turnover.

A question that arises when talking about “recycling” a vehicle that would potentially be retired is, if these vehicles are practical or suitable for the targeted consumer. Can they function as the consumer needs and do so comfortably? Considering the number of vehicles in the fleet, the answer would be yes. There are enough vehicles out there, that could be converted practically, at low costs, and accomplish what the consumer requires. This doesn’t mean every vehicle would be suitable. Quality issues would need to be considered when approving a conversion so that low-income consumers are left with sub-par vehicles, or dangerous vehicles. There will be some vehicles that don’t make for good conversions. A converted vehicle may not function as the consumer needs. The variety of uses, and vehicles makes it certain that there would be enough vehicles out there that could be converted in a practical manner that works for most consumers who are looking for a low-cost option.

It is conceivable that criticism would point out the disparity in vehicles between income groups. The conversions may not appear equitable, but with the scarcity of used EVs, this presents an option, until there is a substantial stock of EVs in the secondhand market. It could also be worth considering expanding the program to those who can afford and EV but chose to convert, if there's concern for a stigma.

Looking at some of the conversion estimates not used in the analysis, a few could be cost-competitive with new BEVs if included in the analysis. This presents another opportunity and benefit of incentivizing the conversion of existing ICEVs. Some of the ICEVs that will continue to remain on the road into the future do so because of personal preference, and not economic limitations. Though it would be an example of middle-income or high-middle income consumers using subsidies, when they may not have otherwise needed, this may not necessarily present an example of "free-riding." It is not a clear assumption that these collectible or sentimental vehicle owners would convert a treasured vehicle absent a rebate, or convert it within the time frame of a rebate program. The existence of boutique conversion shops shows there's some level of demand and providing incentives could push more consumers to convert to EV. The size of this market is very small, so its environmental impacts would likely be very limited.

A second, positive way of considering expanding rebates to boutique retrofits is that it would give experience and help establish practices and standardization to an emerging industry. This would be an example of a positive "network externality", where early adopters are providing positive external benefit to future users by establishing set costs, experience, and best practices. Allowing more widespread use of rebates for retrofits could allow boutique shops to lay the groundwork of the industry through “learning by doing” and reducing risk for other entrepreneurs and consumers (Greene; et al, 2014).

Increased battery efficiency could lower the cost of conversion, but this study has opted to view efficiency conservatively, due to the uncertainty in results from the large variability in vehicles and conversion methods. If efficiency were increased, we would consider that as an added benefit to the consumer, resulting in a vehicle with greater range, but priced the same. Keeping the range constant at 150 miles would decrease the battery pack price by less than $2000. Indexing the low-end costs and increasing fuel economy to 3 mi/kWh results in an increase of range from 150 miles to 225 miles.

The PowerBatteryMean battery-pack cost discrepancy, though the most extreme, was not uncommon; other estimates not included had battery prices in the $300/kWh area. Batteries are the single largest cost of building or converting an EV. Battery prices have reduced substantially, and the use of this model shows that there’s greater potential for converting vehicles at low costs. A business that is focused on converting a variety of vehicles for a variety of consumers would be able to purchase battery packs in greater quantities and benefit from bulk purchasing (scale economies) that current boutique shops cannot achieve.

The program's large monetary benefits were very surprising. This is primarily explained by the amount of money saved by fuel switching to electricity. These benefits are supported by Green, et al., who found that “although substantial costs must be borne upfront, the net present value of the transition to e-drive vehicles appears to be very large...analysis indicates that it may be possible for a transition to electric drive vehicles to produce benefits that exceed the excess costs of a transition by an order of magnitude or more (Green, et al., 2013).”

Further study is required to quantify the benefit of increasing EV share among low-income consumers. The NPV calculations accounted for program size, and program cost. However, larger rebates always resulted in higher costs and lower benefits over 10 years. Without a vehicle limit or program costs limitations, a program would be able to better measure how large rebates would induce more EV conversions.

A benefit that was not analyzed in this study, but is worth mentioning is that there are carbon emissions reductions to be found in conversions, compared to new EV purchases. The production of BEVs is more carbon-intensive than the production of a comparable ICEV. This is the result of the high emissions intensity of battery production. ICEVs are much more carbon-intensive in use and it takes a few years or few thousand miles for BEVs to overcome the increased upfront production emissions. Emissions from battery production would still be relevant to a retrofit, however, the emission from the production of the glider would be avoided.[11] Ambrose et al. collected data and found the average production of a glider to be 8298kg CO_2e. Battery system production emissions account for 28-51% of total production emissions for BEVs (Ambrose et al. 2020). Conversion has the extra benefit of decreasing the carbon “payback” period; the time and distance it takes for the emissions savings of an EV to surpass the emissions of production. A conversion would be and EV which has recycled the glider, reducing a significant source of emissions.

[11] Emissions from the production of the electric motor and controller needs to be considered. No data was found for these components.

6. Conclusion

Transportation emissions are the largest source of GHG emissions in the United States. Emissions from the LDV fleet account for 33% of the US's total emissions. Keeping warming below 1.5℃ will require rapid decarbonization of transport. The best way to achieve this is through increased EV share of vehicles, and decarbonization of the electricity grid. There are major barriers to accomplishing this goal. The turnover of vehicles prevents rapid penetration of EVs into the fleet and is a large source of committed emissions. Low-income consumers cannot participate in the EV marketplace due to high vehicle costs and lack of lower cost used EV options. This results in low-income consumers continuing to create demand for used ICEVs which is a barrier to increased fleet turnover.

To increase EV share and transportation decarbonization, policies must be designed to increase fleet turnover and remove carbon-emitting vehicles from the road. Policies must provide incentives for replacing ICEVs with EVs. Policies must provide low-income consumers low-cost EV options, so they can increase EV share, and avoid increasing vehicle survival. A program that provides rebates for retrofitting combustion vehicles to electric will accomplish these goals. It provides a low-cost EV option, and with progressive rebates, becomes affordable to the most disadvantaged communities, increasing the number of consumers that can increase EV share. The program would have large economic benefits by saving large groups of vulnerable people thousands of dollars in fuel costs. The complications and inconsistency in ICEV to EV retrofits have left the concept to hobbyists and boutique shops. A program to encourage retrofits could provide a great way to decarbonize transportation and provide an equitable means to provide clean transportation to disadvantaged communities.

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APPENDIX

Appendix A

QUOTATION Jul-13

ELECTRIC VEHICLES OF AMERICA, INC.
P.O. BOX 2037 615 CENTER STREET
WOLFEBORO, NH 03894
(603) 569-2100
FAX (603) 569-2115
Sales@EVAmerica.com

AC-51 SYSTEM 144V
USING 12V BATTERIES
MINOR CHANGES FOR LITHIUM CELLS

UNIT TOTAL

QTY DESCRIPTION PRICE PRICE DRIVE SYSTEM

1 HPEVS AC-51 System with Curtis 1239-8501 Controller $4,750.00 $4,750.00 Includes motor, controller, generic harness
and Curtis 840 gauge MSRP $5150

1 PB-6 Curtis Potbox $90.00 $90.00 1 Kilovac Czonka EV200 Contactor $190.00 $190.00 1 Adapter Plate with Spacers (2) $400.00 $400.00 Manual Transmission - Clutchless
1 Motor Coupling (Aluminum) $325.00 $325.00

BATTERY SYSTEM

1 PFC-2500 110 VAC / 230 VAC 144VDC Sealed Charger $725.00 $725.00 Programmed for specific batteries - require mfr's information

24 2/0 Battery Terminal Protective Covers (Red & Black) $1.50 $36.00 50 ft 2/0 UltraFlex Cable (Orange) $5.00 $250.00 40 2/0 lugs - Magna lug (includes 6 90 degree) $2.50 $100.00 6 ft Heat Shrink with sealant $6.00 $36.00

INSTRUMENTATION

1 80-180 Voltmeter (Westberg 2in Black) $75.00 $75.00 1 0-500 Ammeter (Westberg 2in Black) $75.00 $75.00 1 50 mV Shunt - 500A $35.00 $35.00

POWER BRAKES

1 Gast Vacuum Pump (12V) $325.00 $325.00 1 SquareD Vacuum Switch $175.00 $175.00 1 In-line Fuseholders with 20 Amp Fuse $5.00 $5.00

SAFETY

1 Littelfuse L25S-400 $80.00 $80.00 1 Littelfuse holder $30.00 $30.00 1 KLK Fuse & Holder - HV Control Wiring $20.00 $20.00 1 Pair Anderson connectors SBX-350 (Red) $64.00 $64.00 1 Fuseholder (4) - Control Board $20.00 $20.00 1 First Inertia Switch - Auto Shutoff (12V Sys) $45.00 $45.00 1 ElCon DC-DC Converter 132-168VDC Sealed Unit $250.00 $250.00 Recommended for headlights, wipers, etc.

TECHNICAL ASSISTANCE

A/R EVA calculations N/C 1 EVA Installation Manual N/C Includes schematics, drawings, etc.
1 Safety First & S-10 Conversion Video DVD N/C A/R On-Line Assistance @ EVAmerica@aol.com N/C 1 year Subscription to EVAmerica NC ---------------
SUBTOTAL $8,101.00 EVAmerica Package Discount -$161.00 ---------------
TOTAL (Shipping - not included) $7,940.00

New Hampshire has no Sales Tax!

This saves people in some states - hundreds of dollars!

OPTIONAL EV COMPONENTS
TO REPLACE OR SUPPLEMENT ABOVE

INSTRUMENTATION

1 0-400 Ammeter (Westberg 2in Black) $75.00 $75.00 1 50 mV Shunt - 400A $35.00 $35.00

POWER BRAKES

1 Vacuum Gauge (Initial Set-up) $15.00 $15.00

SAFETY

1 Littelfuse L25S-400 (Spare) $80.00 $80.00 1 Pair Anderson connectors SBX-350 (Black) $64.00 $64.00 1 Pair Anderson connectors SB-50 (Red) $20.00 $20.00 1 1500-watt Electric Heater Components $220.00 $220.00

(Heater, mount, contactor, Anderson SB-50 connector, fuse)

14 ft - 1 1/2 inch clear vinyl hose for 2/0 cable protection $1.50 $21.00 10 Insulated Metal Clamps for Vinyl Hose $1.00 $10.00

Appendix B

VEHICLE SURVIVAL RATES

Age		
Years	Passenger Car Survival Rate	Light Truck Survival Rate
0	1	1
1	0.997	0.991
2	0.994	0.982
3	0.991	0.973
4	0.984	0.96
5	0.974	0.941
6	0.961	0.919
7	0.942	0.891
8	0.92	0.859
9	0.893	0.823
10	0.862	0.784
11	0.826	0.741
12	0.788	0.697
13	0.718	0.651
14	0.613	0.605
15	0.51	0.553
16	0.415	0.502
17	0.332	0.453
18	0.261	0.407
19	0.203	0.364
20	0.157	0.324
21	0.12	0.288
22	0.092	0.255
23	0.07	0.225
24	0.053	0.198
25	0.04	0.174
26	0.03	0.153
27	0.023	0.133
28	0.013	0.117
29	0.01	0.102
30	0.007	0.089
31	0.002	0.027

Source: U.S. Environmental Protection Agency, Draft Technical Assessment Report: Midterm Evaluation of Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards for Model Years 2022-2025, EPA-420-D-16-900, July 2016.Assessment Report: Midterm Evaluation of Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards for Model Years 2022-2025, EPA-420-D-16-900, July 2016.

Appendix C

Li-Ion Price Table

Cost ($/kWh)	$300	$280	$250	$200	$160	**$137**	$100	$68			
Energy(kWh)										Distance (2m/kwh)	Distance (3m/kWh)
5	$1,500	$1,400	$1,250	$1,000	$800	**$685**	$500	$340		10	15
10	$3,000	$2,800	$2,500	$2,000	$1,600	**$1,370**	$1,000	$680		20	30
15	$4,500	$4,200	$3,750	$3,000	$2,400	**$2,055**	$1,500	$1,020		30	45
20	$6,000	$5,600	$5,000	$4,000	$3,200	**$2,740**	$2,000	$1,360		40	60
25	$7,500	$7,000	$6,250	$5,000	$4,000	**$3,425**	$2,500	$1,700		50	75
30	$9,000	$8,400	$7,500	$6,000	$4,800	**$4,110**	$3,000	$2,040		60	90
35	$10,500	$9,800	$8,750	$7,000	$5,600	**$4,795**	$3,500	$2,380		70	105
40	$12,000	$11,200	$10,000	$8,000	$6,400	**$5,480**	$4,000	$2,720		80	120
45	$13,500	$12,600	$11,250	$9,000	$7,200	**$6,165**	$4,500	$3,060		90	135
50	$15,000	$14,000	$12,500	$10,000	$8,000	**$6,850**	$5,000	$3,400		100	150
55	$16,500	$15,400	$13,750	$11,000	$8,800	**$7,535**	$5,500	$3,740		110	165
60	$18,000	$16,800	$15,000	$12,000	$9,600	**$8,220**	$6,000	$4,080		120	180
65	$19,500	$18,200	$16,250	$13,000	$10,400	**$8,905**	$6,500	$4,420		130	195
70	$21,000	$19,600	$17,500	$14,000	$11,200	**$9,590**	$7,000	$4,760		140	210
75	$22,500	$21,000	$18,750	$15,000	$12,000	**$10,275**	$7,500	$5,100		150	225
80	$24,000	$22,400	$20,000	$16,000	$12,800	**$10,960**	$8,000	$5,440		160	240
85	$25,500	$23,800	$21,250	$17,000	$13,600	**$11,645**	$8,500	$5,780		170	255
90	$27,000	$25,200	$22,500	$18,000	$14,400	**$12,330**	$9,000	$6,120		180	270
95	$28,500	$26,600	$23,750	$19,000	$15,200	**$13,015**	$9,500	$6,460		190	285
100	$30,000	$28,000	$25,000	$20,000	$16,000	**$13,700**	$10,000	$6,800		200	300